U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Passenger Cabin Smoke Evacuation	**Date:** DRAFT 8/9/02 **Initiated By:** ANM-115	**AC No:** 25.795-(b)(2) **Change:**

WORKING DRAFT -- NOT FOR PUBLIC RELEASE.

1. **PURPOSE**: This Advisory Circular provides a means, but not the only means, of compliance with § 25.795(b)(2), and discusses the rulemaking action which implements ICAO Annex 8, Appendix 97 Standards, pertaining to an aircraft design requirement that there be means to remove smoke, fumes and noxious vapors, such as might be produced by an explosive or incendiary device, from the passenger cabin in flight. It is the intent of this requirement that, after such means are implemented, the cabin environment does not reach smoke, fume or noxious vapor concentration levels that are incapacitating.

2. **RELATED FAR SECTIONS**: Title 14, Code of Federal Regulations (14 CFR) Parts 25 and 14 CFR §§ 25.795. 25.831, 25.857

3. **DISCUSSION**. The International Civil Aviation Organization adopted certain requirements related to security aspects of airplane design in amendment 97 to Annex 8. Included is a requirement that the airplane have the capability to evacuate smoke, fumes and noxious vapors from the passenger cabin, such as might be produced by an explosive or incendiary device. This requirement is adopted into the Federal Aviation Regulations as new section 25.795(b)(2)

   a. Smoke removal, general. Prior to adoption of Amendment 25.XX there were no requirements related to removing smoke from the passenger cabin, although most manufacturers provided procedures to their customers. These were based on best practices for their system, regardless of the smoke source or intensity. There are effectively no bounds on the amount of smoke that could be generated but there are clearly bounds on airplane systems capabilities in removing smoke. A smoke removal requirement must set the boundaries based on rational premises. In that light, a general smoke removal procedure must assume that the source of the smoke is extinguished. Once extinguished, there is a finite quantity of smoke that must be removed from the occupied area within a certain amount of time to provide for acceptable environmental conditions. Aside from the reason mentioned, general smoke removal procedures are not believed suitable if the source of the smoke, presumably a fire, is still producing smoke, as discussed below.

b. Smoke removal, specific. In those cases where the fire is not extinguished, there may well be acceptable procedures for removing smoke. However, due to the unknowns present with a fire, there is the potential that the smoke removal procedures will worsen the situation. That is, an acceptable procedure in one situation may be detrimental in another. There are several reasons for this. First, the location of the fire could be such that the means used to evacuate the smoke serves to provide ventilation to the fire, thereby intensifying it. Second, the dynamics of the fire itself can dramatically change the ventilation patterns from their normal flow. Third, removing the smoke may only convey the sense that the fire is out (i.e., the evidence is gone), even though it could be continuing to burn. Of course, there are situations where the procedure should be used regardless, when it is deemed necessary by the crew.

c. Fire Characterization. For the purposes of this requirement, the ignition source of the fire is considered to be an explosive or incendiary device. Data from tests with these types of devices indicate that the fire that results from such a device is mostly dictated by its location in the airplane and materials present, rather than the device itself. The fire is a function of the geometry and quantity of material available. This leads to two important conclusions/assumptions regarding demonstrating compliance:

   (1) The fire is a surface burning fire and can therefore be reasonably expected to be extinguished by personnel or a built-in system. This is important because, as noted above, smoke removal procedures can only be assumed to be effective, and in many cases advisable, once the fire is out.

   (2) The amount of material available to a fire can be expected to increase with the size (cabin volume) of the airplane, which in turn will increase the amount of smoke and gases generated. This relationship ties smoke quantity to cabin volume, the ratio of which is assumed constant for any airplane size for the purposes of this guidance. For airplanes with more than one passenger deck, each deck should be addressed independently.

4. **SPECIAL CONSIDERATIONS**: The following special considerations shall be observed:

   a. No structural or systems damage need be considered. The airplane structure and the systems are assumed to be functional after the detonation of an explosive device. No reduction in performance is assumed in systems operations or airplane capabilities.

b. The airplane must be assumed to be operating under any phase of flight. The applicant shall provide cabin smoke, fumes and noxious vapor removal, regardless of the location and origin of the fire and during any flight phase, except for the following. This does not apply to short duration air conditioning "packs off" operations during take-off and initial climb, "packs off" operations during a "go-around", landing procedures requiring a "hold" in the descent phase, or during idle descent operations.
c. The flow behavior of toxic gases is assumed to be identical to visible smoke. The detection and removal of smoke is assumed to equally remove any toxic gases that are present. No other design requirements or analysis will be required other than specified.
d. Fresh air must be used to clear the smoke from the passenger cabin. Fresh air must be used for analysis or testing for the purposes of showing compliance.
e. If a smoke demonstration clearance procedure is used to show compliance, smoke may migrate to any part of the airplane, except the flight deck, before vented overboard.

5. **COMPLIANCE**: Requirements related to smoke protection of the flight deck continue to apply and actions taken to address compliance with § 25.795(b)(2) should have no adverse effect on the flight deck smoke penetration minimization or smoke removal.

a. Cabin Airflow Performance. Based on a review of full-scale fire test data, the FAA has established relationships of the hazard level within a certain volume of the passenger cabin over time. Examples are given in Appendix 1. One means for compliance is to remove smoke from the passenger cabin through uninterrupted changes of cabin air with fresh air. FAA has determined that an air change rate of once every five minutes for at least a 30 minute continuous period meets the compliance requirement and is sufficient to prevent smoke hazardous levels from becoming incapacitating. It is noted that this is considered an emergency procedure and not necessarily the normal operating regime of the ventilation system. It is expected that the system provide sufficient capacity for the duration of time necessary to evacuate the smoke and then could be restored to normal operation. Alternatively, special valves might be installed to effect evacuation, although the effect on cabin pressurization would have to be considered so that no other hazard to occupants is created. This would include both the rate of pressure loss as well as the absolute cabin pressure. Demonstration of compliance for this requirement would be through analyses or tests.

(1) Analyses. For the analyses, the applicant would need to show that the required fresh air can be provided for all flight conditions except as noted in section 4.(b), taking into consideration variations in the capability of the air source.

I. When performing these analyses, the applicant may account for the following:
   i. Take credit for all fresh air entering the passenger cabin volume that will aid in removing contaminants;
   ii. Compute the passenger-cabin volume from those compartments that would be expected to contain passengers and crew, excluding the flight deck and crew rest within the flight deck and isolated crew rests (remote crew rests not located on the passenger deck), during the smoke evacuation. The passenger floor, sidewall and ceiling liners, and overhead stowage bins define the perimeter boundaries to the passenger-cabin volume, as illustrated in Figure 1. The fore and aft limits are defined by the flight deck bulkhead and aft passenger-cabin boundaries.

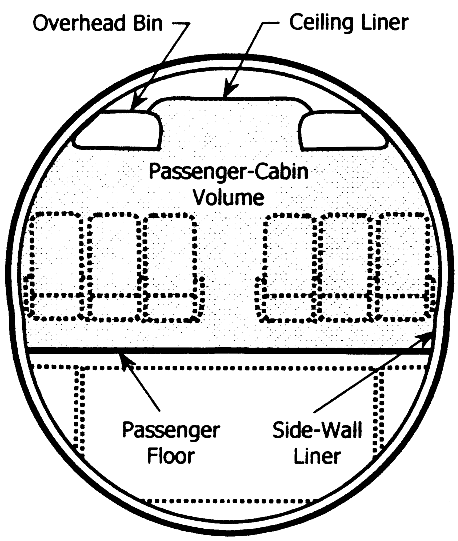

Figure 1. Region within Fuselage Cross Section That Defines the Outer Boundaries of the Passenger Cabin Volume

II. The air change rate is defined as:

$$Air\ Change\ Rate = \frac{Passenger\ Cabin\ Volume\ (ft^3)}{Fresh\ Airflow\ (ft^3/min)}$$

It is not necessary to consider individual cabin zones when computing air change rates.

(2) Tests. If a test is chosen to demonstrate compliance, the cabin smoke removal procedures in AC 25-9A will be followed. Small amounts of smoke are allowed to remain in parts of the passenger cabin since complete homogeneous mixing of fresh air with smoke would not be expected.

b. Protective Breathing. An applicant would have to define to the satisfaction of the administrator how he would accomplish either b.(1) or b.(2) of this section. The objective of any alternative approach should be to keep the fractional effective dose below 1, as per Appendix 1. To that end, initial conditions need to be defined that are consistent among models. Appendix 2 provides data from testing and the resulting initial conditions that should be used if alternative methods of compliance are utilized.

(1) The approach described above is aimed at direct evacuation of smoke from the passenger cabin. An alternative procedure might be to provide cabin occupants with protective equipment that would be a means of avoiding the hazard, rather than eliminating it. In that case, the equipment would need to provide protection for the duration of the flight, assuming worst-case diversion times. Note that any protective devices for inflight use should not compromise evacuation. Generally, this would mean that the devices would be accessible only when necessary in-flight. Various studies have shown that protective breathing devices can degrade evacuation times because passengers devote considerable time in donning the equipment rather than exiting the airplane.

(2) A combination of smoke evacuation and protective equipment for the occupants might also be an option. In this case, procedures would need to be developed to account for various scenarios, such that the combination would be effective. Appendix 1 shows a typical FED curve for passengers using oxygen masks.

c. Additional Alternatives. If another method of compliance is used for any airplane configuration, the applicant must show that his method will prevent the FED (as explained in Appendix 1) value from reaching 1.0 with an initial combined volumetric concentration of 0.59% carbon monoxide and 1.23% carbon dioxide in the passenger cabin. The value provided in Appendix 2 may be used in supporting the applicant's method.

d. Combination Passenger/Cargo Arrangements. It should be noted that the basic assumptions used to establish smoke quantity and air change rates were based on typical passenger carrying arrangements. For combination passenger/cargo ("combi") arrangements, the same approach would tend to yield higher initial concentration values and therefore a higher rate of air change required to maintain an FED below 1. This is because the volume of the cargo compartment is large with respect to the volume of the passenger compartment. For the purposes of this requirement however, the assumptions made to arrive at the required air change rate for passenger airplanes are considered acceptable for combi airplanes and the methods of (a) and (b) of this section would be acceptable for those airplanes as well.

<u>Appendix 1</u>

1. **<u>BASIC PRINCIPLES</u>**: Determining an acceptable means of compliance requires knowledge of several parameters, as well as establishing suitable success criteria. The following discusses each of the relevant parameters and the means of establishing environmental conditions that will prevent incapacitation, defined by an FED of 1, as explained below.

   a. <u>Hazard parameters</u>. The hazards to passengers from cabin smoke can be characterized by the toxic gases and the time variation of their concentrations. If it is assumed that the airflow patterns within the passenger cabin maintain a steady outflow with uniform mixing of fresh air, then the variation of smoke concentration over time will be in the form of an exponential decay, as shown in chart 1 of this Appendix, and is described by the equation:

   $$C(t) = C_o e^{-(t/\tau)}$$

   Where,
   C(t) is percentage concentration of smoke, by volume, as a function of time
   C_0 is the initial percentage concentration of smoke, by volume
   t is passenger smoke exposure time (minutes)
   τ is the time for one cabin air change (minutes)

   A number of simplifying assumptions have been made in defining the relationship as noted above. For example, the effects of diffusion within a space are not considered, as these will vary from airplane to airplane and significantly complicate the calculation. However, preliminary analyses, considering diffusion, indicate that the simplified approach correlates sufficiently well to define a compliance approach.

   Assuming the passenger-cabin air change rate, τ, is known, the initial concentration will establish the concentration reductions for all other times. This concentration model describes the time relationship for a specific gas in a given volume. Each gas that is considered hazardous is assumed to behave in the same manner. Carbon monoxide and carbon dioxide are two consistently common byproducts of combustion and are used to characterize all hazardous byproducts from a fire. The time variation in concentrations of each is modeled separately to assess their combined effect on human tolerance. Establishing the basis for this initial concentration level is pivotal to the basic problem of smoke evacuation and the following provides the rationale used:

      (1) A review of available test data reveals that the most relevant data relates to cargo-compartment fires. The FAA has data available to characterize the concentrations of smoke and gases produced by such a

fire at the time it was extinguished. The cargo-compartment fire is considered a good basis for assessing hazards since it can be readily detected and extinguished, if a surface fire. In addition, the cargo compartment is considered a possible location for a device of this type, so it is appropriate to use data that is derived from cargo-compartment fires.

(2) In order to quantify the initial smoke density in passenger cabins from test results, it is necessary to equate the smoke data from cargo compartments to passenger cabins. This can be accomplished by compensating for the volume differences between the two. For example, if the initial concentration for a particular gas were 2% by volume in a 100-ft^3 cargo compartment, this would translate to a concentration of 0.2% in a 1000-ft^3 passenger compartment. However, because the explosive device is a localized event, it is likely that the smoke and gases would initially be restricted to a confined area of the cabin before they had time to disperse. While the resultant distribution of smoke and gases over time would likely involve the entire cabin, by treating the local area as an independent volume from which the smoke and gases must be evacuated, a conservative assessment of the hazard can be made. It is therefore assumed that the smoke and toxic gases are confined to $1/4^{th}$ of the cabin volume. So, in the example above, the initial concentration used for the hazard assessment would be 4 times 0.2%, or 0.8% by volume. This initial smoke concentration value, C_0, would then be used to calculate the concentration decay over time.

(3) Based on the test data and this volumetric relationship between cargo compartments and passenger-cabin size, FAA has determined that the initial combined volumetric concentrations of 0.59% carbon monoxide and 1.23% carbon dioxide be assumed in the passenger cabin when determining occupant protection against smoke incapacitation. These initial conditions are also contained in Appendix 2.

(4) There is no distinction between smoke, its constituents, and other potentially hazardous products of combustion in terms of their dissipation rates over time. That is, all particulates and gases are assumed to maintain their relative percentages within the smoke, even though their absolute percentages relative to the cabin air diminishes with time.

b. Passenger Hazard Characterization. There are numerous methods available to assess hazard and numerous variations on each of them. One generally accepted method is a "Fractional Effective Dose" (FED) hazard model. FED considers the cumulative effects of varying exposures over time to various contaminants. There are several variations of FED that may include temperature, smoke density and various gases. However, these parameters largely depend on, among other elements, the associated products of combustion for any particular fire. Since there is no way to predict the fuel for the fire, it is necessary to use representative data to establish a standard. The FED is described in the general form:

$$FED = \Sigma_1^n FED_i$$

Where FED_i is the fractional effective dose for a given hazard, with *n* representing the total number of hazards considered. Each constituent product of combustion has its own relationship to toxicity over time. An FED value of 1 or greater would indicate, for these assessments, passenger incapacitation. Using data from the FAA's fire testing program, carbon monoxide has the greatest contribution to FED. Carbon dioxide causes increased respiration rates, which magnifies the effect of carbon monoxide. These two parameters tend to dominate the FED calculation for the data used by the FAA in developing this guidance. See chart 2 in this Appendix for graphical examples of FED calculations. Further information on the concept of FED can be found in the Society of Fire Protection Engineers "Handbook of Fire Protection Engineering" and in FAA report DOT/FAA/AR-95/5, "Toxicity Assessment of Combustion Gases and Development of A Survival Model", dated July 1995.

Example Curves:
Chart 1 shows an example of an exponential decay of hazardous gases over time and the change in oxygen concentration that results.

Chart 2 shows an example of both an acceptable and an unacceptable FED profile while using the same baseline data. Note that a small increase in time for an air change is sufficient to drive FED above 1. Also included is an FED curve showing the effect of two minutes of protective breathing equipment used by passengers before exposure to the cabin air.

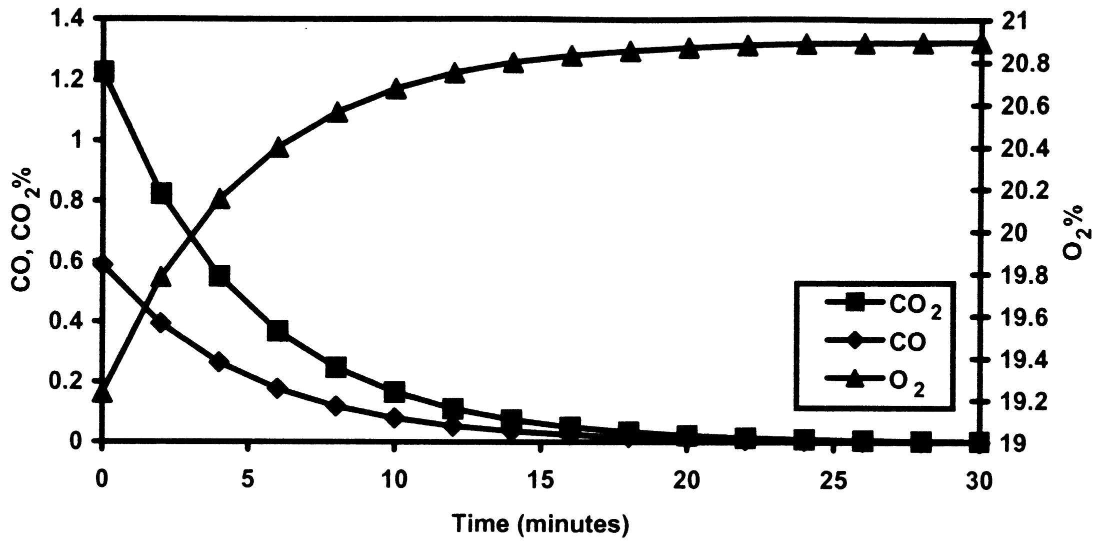

Chart 1. Decay of Toxic Gas Concentrations with an Associated Increase in Oxygen Concentrations Over Time From a Smoke Evacuation With a Five-Minute air Change Rate.

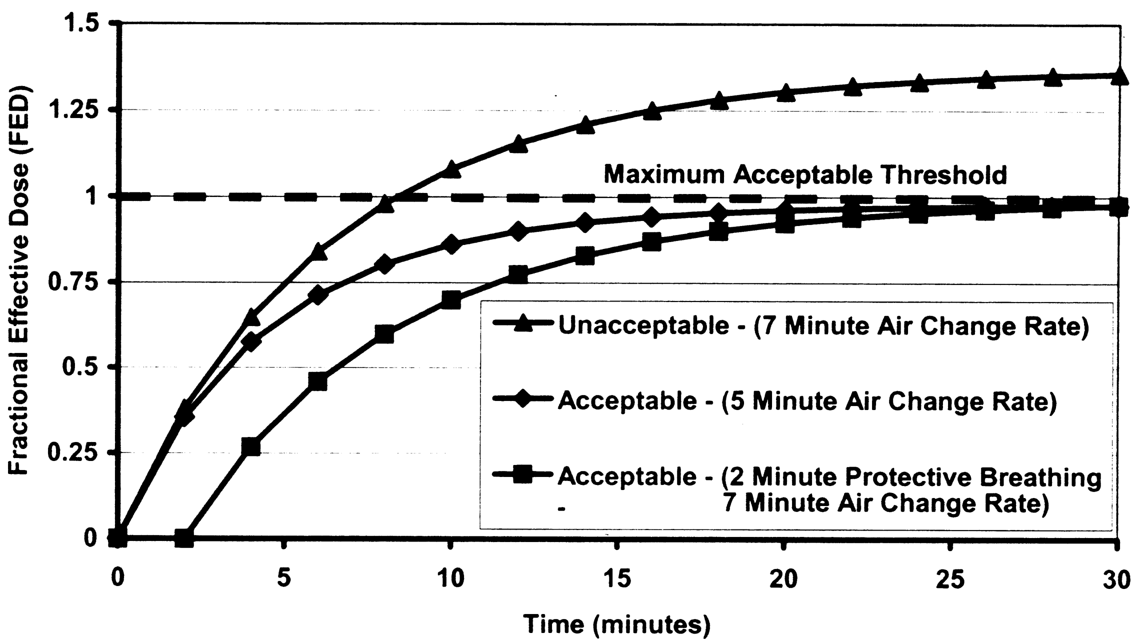

Chart 2. FED Accumulation Curves for a Smoke Evacuation With a 7 Minute Air Change Rate (Unacceptable), a 5 Minute Air Change Rate (Acceptable), and a 7 Minute Air Change Rate Using Protective Breathing Equipment for the First 2 Minutes (Acceptable).

Appendix 2
Initial Concentration Data

The FED curves in Appendix 1 are based on empirical data from full-scale fire tests. In the absence of other rationally generated data, the initial concentrations that should be used in assessing alternative methods of compliance are shown in the right-most column (Initial Concentration in Cabin Area)

Constituent	Initial Concentration From Tests (% Volume)	Initial Concentration in Cabin Area (% Volume)
CO	1.20	0.59
CO_2	2.50	1.23
O_2	17.50	19.23

The data for initial concentrations in the cabin area are based on the volumetric relationship between passenger compartments and cargo compartments. While this relationship is not a constant among all airplanes, there is a range of values and the FAA has selected an acceptable value within this range on which to base these concentrations.

[4910-13]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Parts 25, 121, and

[Docket No. FAA-2001- ; Notice No.]

RIN 2120-AG91

TITLE: Security related considerations in the design and operation of transport category airplanes.

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This notice proposes to amend the regulations governing transport category airplane design to implement certain requirements related to security, many of them recently adopted by the International Civil Aviation Organization (ICAO). These include improved design features and protections for the cabin, flight deck, and cargo compartments from the effects of an explosive device, including fire, smoke, and noxious vapors. The operating requirements would also be amended to require that operators establish a "least risk bomb location" on all airplanes affected and to ensure incorporation of certain information into the operators' relevant manuals.

DATES: Comments must be received on or before [insert a date days after date of publication in the Federal Register].

ADDRESSES: Address your comments to the Docket Management System, U.S. Department of Transportation, Room Plaza 401, 400 Seventh Street, SW., Washington, DC 20590-0001. You must identify the docket number FAA-2003-XXXX at the